

## Qualitative and Quantitative Evaluation of Commercial Non-Stick Coatings

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## Background

Army field feeding operations is burdened by the cumbersome and slow process of sanitizing field cookware. Each day, hundreds of gallons of hot water and hundreds of pounds of heavy equipment are needed clean and sanitize cookware. The act of heating the water heats the tent as well, making the job of scrubbing the piece after piece of equipment difficult and unpleasant. The reason for all the work and scrubbing is stuck-on food. The aluminum pots and pans that are used are notorious for being nearly impossible to clean, if food is burnt on or left in the pan too long before cleaning a wire mesh pad is used to scrape it. Over time, the aluminum becomes corroded and pitted making the job even harder or even impossible. Pitted cookware is a haven for bacteria growth and over time, the cookware becomes unusable and is discarded.

The addition of a non-stick coating would solve many problems. It would greatly reduce the time and effort needed to scrub the dirty cookware. Secondly, less water is needed in the sinks because most of the food waste can be scraped off the pan before it is introduced to the washing and sanitizing process, which translates to less greywater discharge. This means less energy consumption for heating the water and subsequently a more adequate working environment. The use of a non-stick coating would also protect the pan from corrosion extending the life of the pan, as well as insuring safety from food pathogens. Finally, non-stick coatings allow for the possibility of waterless sanitation techniques including sanitizing wipes. Cloth wipes impregnated with non-rinsing sanitizing detergents will be effective at sanitizing non-stick cookware that is wiped clean.

The largest problem with traditional non-stick coatings is their short life cycle. Scratching, flaking and peeling are all common to commercial and professional non-stick coatings. Great care must be taken to protect the coating from contact with metal utensils and abrasion of any kind. There is no guarantee that the rigors of the field will be kind to the coating. During desert operations, it is common for sand to find its way into every crevice of equipment on a truck and the addition of plastic utensils is unlikely, as they are known to melt.

Several novel non-stick coatings that are currently on the market claim hardness and wear resistance far exceeding that of typical cookware coatings. This study will evaluate these novel coatings for their performance on cookware.

## **Introduction**

The commercial market for Teflon™ type polytetrafluoroethylene (PTFE) coatings has advanced rapidly in the past five years increasing the options and technologies from which to choose. Several different manufacturing techniques have been implemented in attempts to optimize the PTFE coating's non-stick properties. Furthermore, non-Teflon type coatings such as ceramic and metal coatings have advanced to compete with the PTFE coatings. Other coatings integrate PTFE into a 'matrix' with metals, ceramic or both. This series of tests will help to determine which coatings will continue to exhibit good release properties and adherence to the pan over time. Five coatings were selected for testing: PTFE, hard anodized, a ceramic impregnated with PTFE and metals, a nickel coating impregnated with PTFE, and a hard anodized coating impregnated with PTFE. A bare aluminum surface was used as a control.

The coatings were tested quantitatively with ANSI standard material property tests. The properties of interest include: hardness, thickness, wear resistance, corrosion resistance, friction coefficient, and resistance to heat. Concurrently, the PTFE and ceramic coatings were tested qualitatively by cooking meals on them. Beef roasts and Swiss steaks were cooked in the pans repeatedly until the coatings began to show signs of wear.

This report is divided into two sections qualitative and quantitative. Each section will contain its own results and discussion with a final results and discussion section at the end of the report.

# QUANTITATIVE

## MATERIALS

Five roaster pans were coated with five different coatings. Three proprietary coatings from General Magnaplate were used, Tufram<sup>®</sup>, Plasmadize<sup>®</sup> and Nedox<sup>®</sup>. American Durafilm, Inc. applied a Teflon<sup>®</sup> coating and a hard-anodized coating was applied at Duralectra Co. The pans were then covered with masking tape and cut into 3" x 3" coupons using a high-pressure water jet precision saw.

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### Hard Anodized

Hard anodizing is an electro-chemical process that converts the surface of raw aluminum to an artificial oxide coating. The process uses sulfuric acid as an electrolyte. When an electrical charge is applied, the hard anodize process is sustained on the surface of the aluminum. The coating is usually very thin and hard to remove because half of the coating is impregnated into the metal while the other half is on the surface.

### Teflon<sup>®</sup>

Teflon<sup>®</sup> is a DuPont brand name for a family of fluoropolymers consisting mainly of polytetrafluoroethylene (PTFE). Other fluoropolymer that are considered Teflon<sup>®</sup> are FEP, Tefzel<sup>®</sup> ETFE, and PFA. PTFE, the original resin was introduced in 1946 with others to follow in 1960, 1970 and 1972. Teflon<sup>®</sup> is considered to be the slipperiest coating available on the market.

### Ceramic

Ceramic coatings are much more durable and wear resistant than PTFE coatings. They are also much thicker and applied in several layers. Intense heat is needed to cure them to the base metal and often a plasma spray is used in the application process. Because ceramic coatings are sometimes lacking in good release properties, they are often impregnated with PTFE. Plasmadize<sup>®</sup>, the General Magnaplate coating used in this test, is a ceramic impregnated with metals for added hardness and PTFE for added release properties. It is FDA approved for food processing applications.

## Metallic

Metallic coatings are generally very hard as they consist of a thin layer of a metallic substrate. They are applied in several ways, including electrolysis, vapor deposition or chemically.

## **METHODS**

To evaluate the coatings, 7 parameters were tested: hardness, wear resistance, corrosion resistance, thickness friction coefficient, thermal resistance, adhesion after thermal shock, and. Each test was conducted according to or based on an ASTM standard test.

### Thickness

The thickness is measured by viewing the cross section of the material under a microscope according to ASTM B487-85. The thickness of a coating is important for several reasons. A thin coating may have excellent hardness and wear properties but may not endure because of the lack of depth, once a little is scraped off, there is nothing underneath to fall back on. Very thick coatings however, can disturb the tolerances of a part. The thickness also determines the type of hardness test that must be performed; each test's indenter is rated for a different thickness.

### Hardness

Knoop hardness is a method of measuring a material's hardness by its resistance to indentation. The method uses a precision diamond indenter and loads between 1 and 1000 grams force. The size of the impression is measured with a microscope according to ASTM E18-94 and ASTM B578-87.

### Wear Resistance

Taber abrasion measures a material's resistance to wear by measuring the amount of material scraped off a flat surface by a rotating disk. The disk is rotated for 1000 cycles under a 1000g weight according to ASTM B137-95 and IAW Fed-Std-141.1.

### Coating Adhesion

This test evaluates the adhesion of a coating to a metallic surface. According to ASTM D3359-95a, a pressure sensitive tape is applied and removed over cuts made in the coating. The percentage of coating removed is reported.

### Corrosion Resistance

Corrosion resistance is measured by a salt spray test. According to ASTM B117-97, a salt fog is directed at a material for 1000 hours. The material is then examined for corrosion and subjected to a coating adhesion test according to ASTM D3359-95.

### Thermal Shock

The thermal shock test determines the condition of the coating after it undergoes a rapid temperature change. To shock the coating it is heated to 500°F, cooled to 0°F and reheated to 500°F. The process is repeated 5 times holding the samples at each temperature for 20 to 30 minutes. The adhesion of the coating is then tested according to ASTM D3359-95.

### Thermal Resistance

The thermal resistance test determines the coating's ability to withstand moderately high temperatures for a sustained period of time. The coating is heated to 450°F - 500°F and held there for approximately 100 hours. The integrity of the coating is determined by a tape adhesion test ASTM D3359-95.

### Friction Coefficient

The coefficient of friction determines how slippery a surface is. ASTM D1894-95 gives guidelines for determining both the static and kinetic friction coefficients. Stainless steel was the material run used to against the coating. Each of the General Magnaplate coatings' published friction data is shown in Table 1.

**Table 1: Published Friction Data**

	Static	Kinetic
Plasmadize FT4	0.161	0.153
Nedox SF2	0.166	0.155
Tufram HO	0.171	0.149
Teflon	0.142	0.129

## RESULTS

All tests were conducted by IMR Test Labs, 131 Woodsedge Drive, Lansing Business & Technology Park, Lansing, NY 14882, P.O.# DAAN02-98-P-8652. Tables of results and pictures of samples were published in IMR report #1453.098. Table 2 is a table of the defined quantitative results. Table 3 shows the results from the more qualitative yet rigorous test such as the salt spray and thermal resistance tests. Figures 1-5 are graphs that show a direct comparison of performance for each test.

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**Table 2: Results**

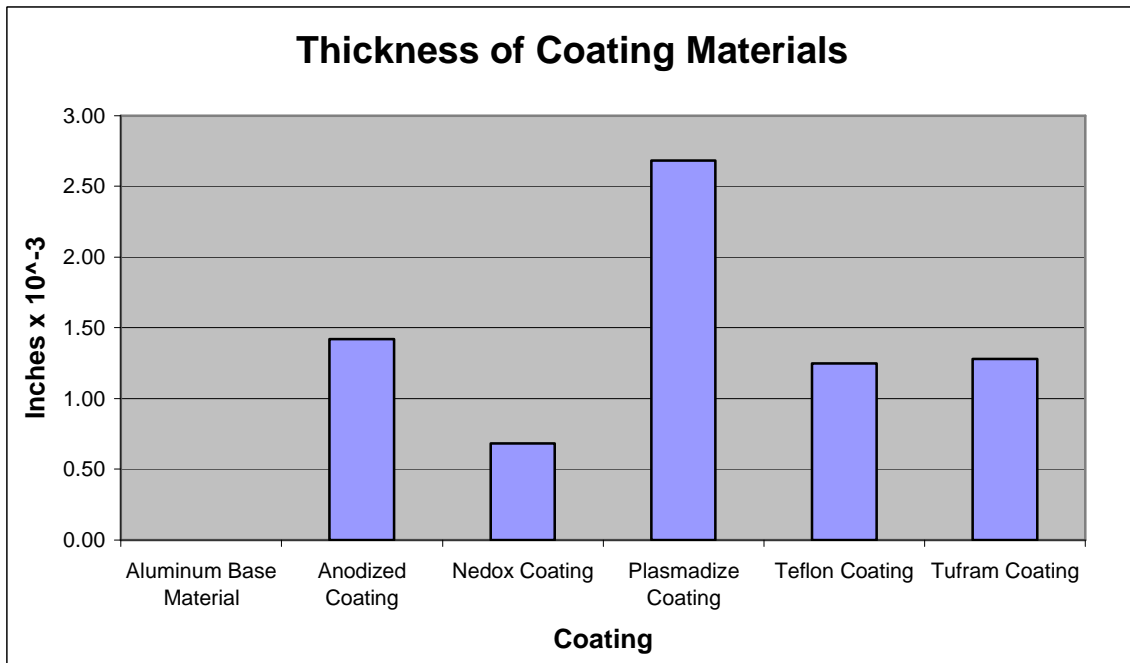
	Thickness Inches x 10 <sup>3</sup>	Knoop Hardness	Taber Abrasion mg lost	Static Coefficient of friction	Kinetic Coefficient of friction
Aluminum Base Material	0.00	N/A	2.45	0.27	0.20
Anodized Coating	1.42	430	0.18	0.29	0.19
Nedox Coating	0.68	961	6.77	0.19	0.17
Plasmadize Coating	2.68	14	4.31	0.20	0.20
Teflon <sup>®</sup> Coating	1.25	too soft to measure	1.45	0.22	0.17
Tufram Coating	1.28	546	1.68	0.21	0.17

**Table 3: Results of Tape Test**

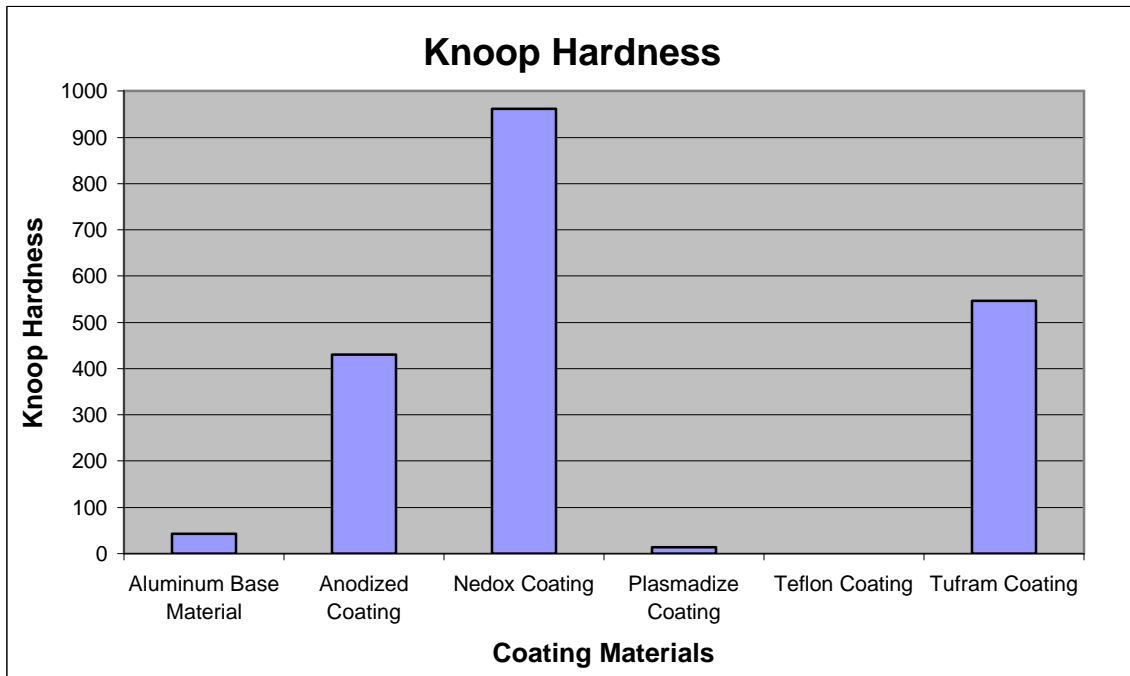
	Salt Spray Exposure**	Thermal Shock	Thermal Shock
Aluminum Base Material	Pass (extensive AlO <sub>2</sub> )	No Damage to surface	No Damage to surface
Anodized Coating	Pass	Less than 5% removed	Less than 5% removed
Nedox Coating	Pass (severe pitting)	Less than 5% removed	Less than 5% removed
Plasmadize Coating	Pass (minor pitting)	Less than 5% removed	Less than 5% removed
Teflon® Coating	Pass (some pitting)	Less than 5% removed	Less than 5% removed
Tufram Coating	Pass	Less than 5% removed	Less than 5% removed

\*\*See figures 6-11 for photos

**Figure 1, Thickness of Coating Materials**



**Figure 2, Knoop Hardness**



**Figure 3, Taber Abrasion**

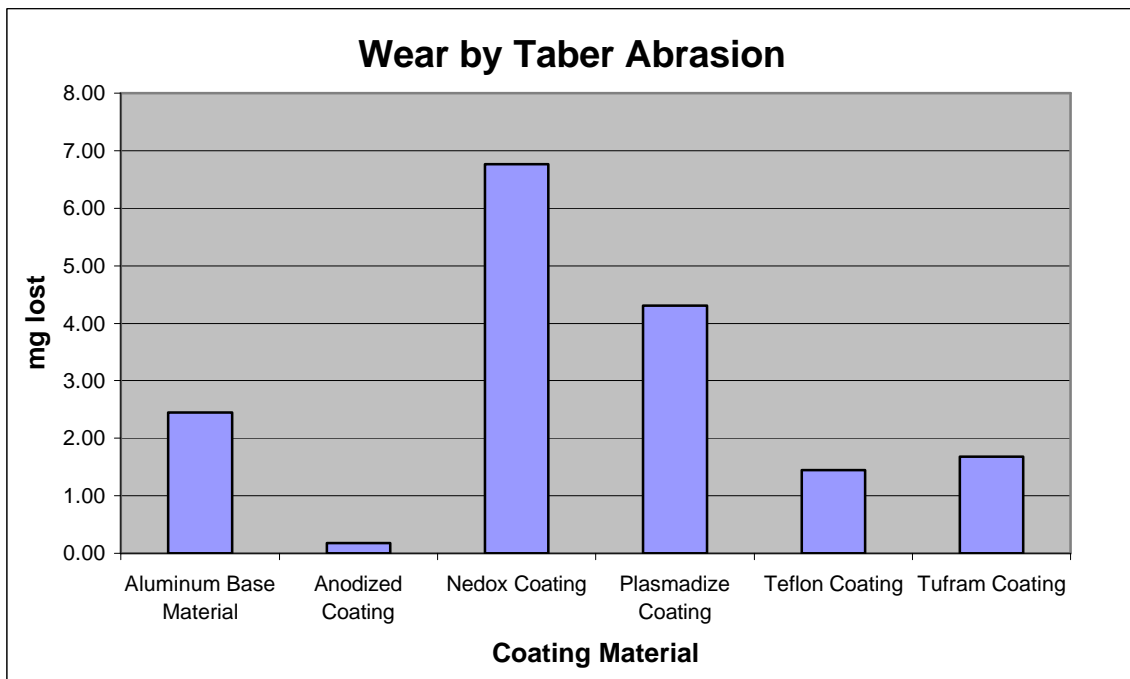


Figure 4, Static COF

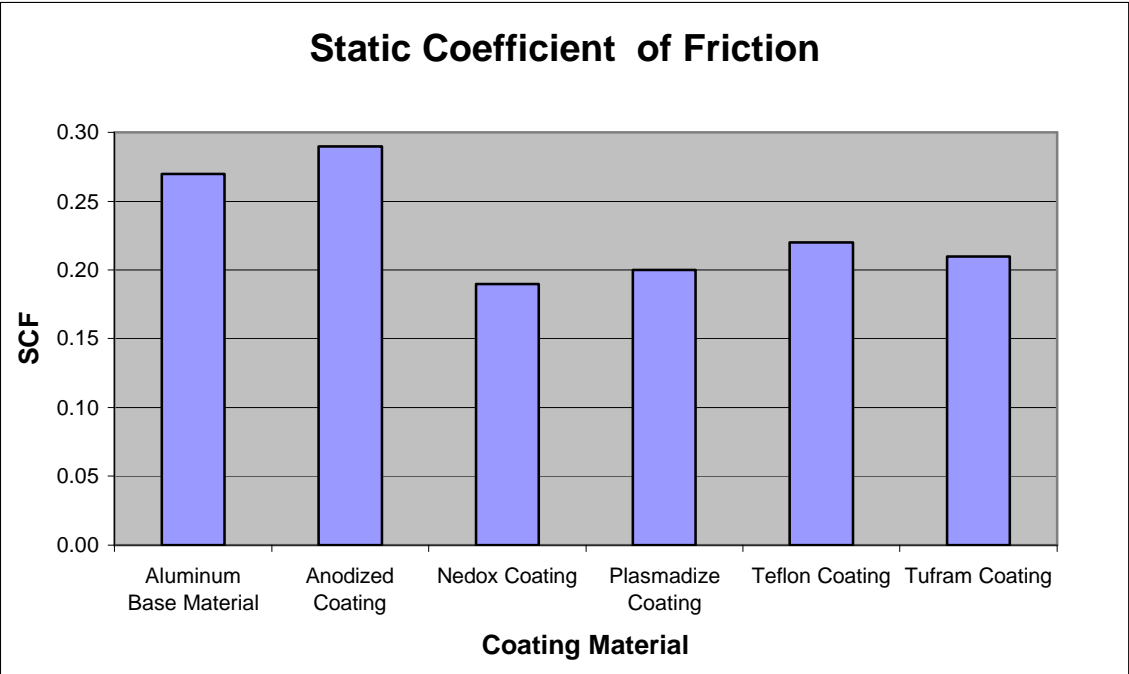
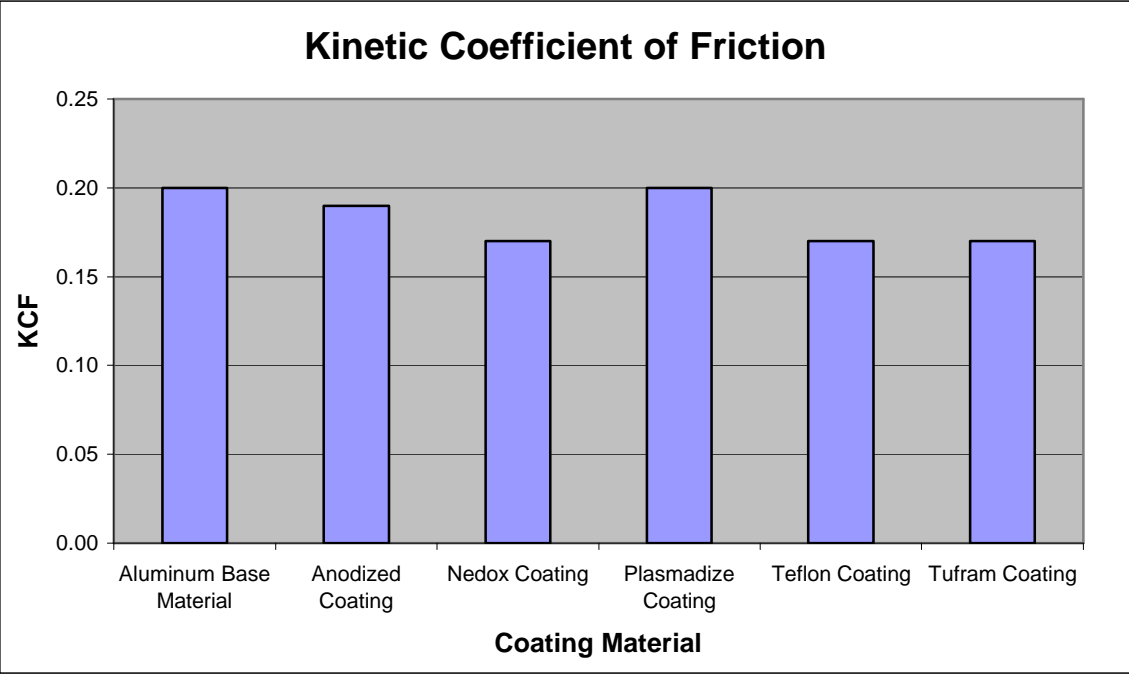
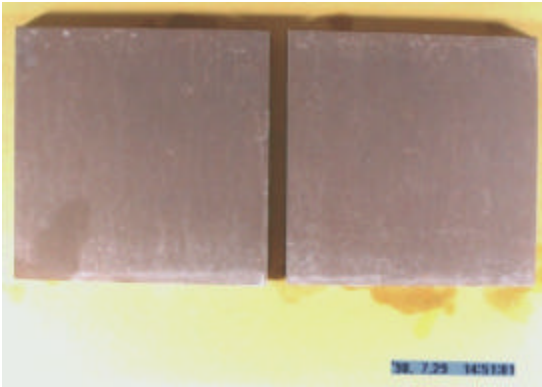


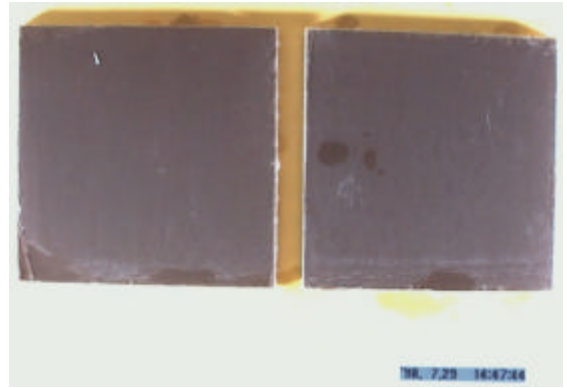
Figure 5, Kinetic COF



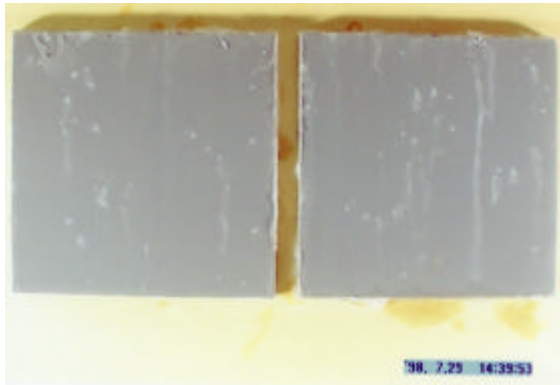
## 1000 Hour Salt Spray Results



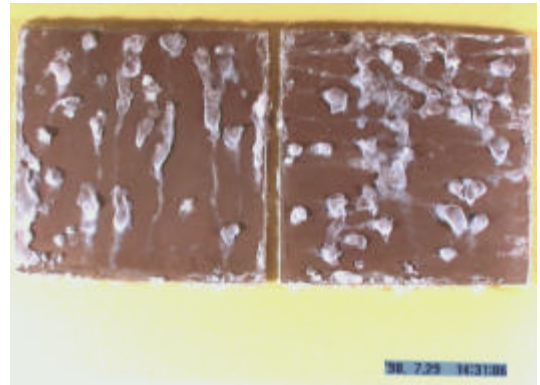
**Figure 6, Base Aluminum – Salt Spray**



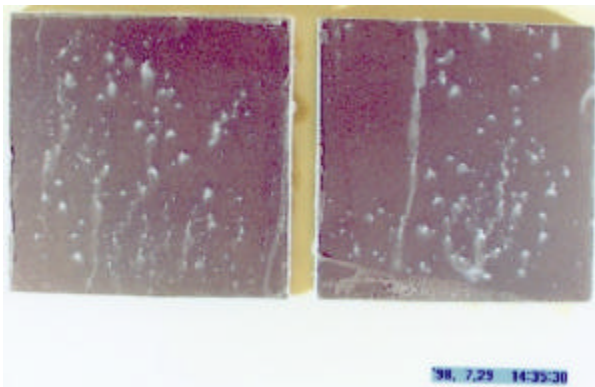
**Figure 7, Hard Anodized – Salt Spray**



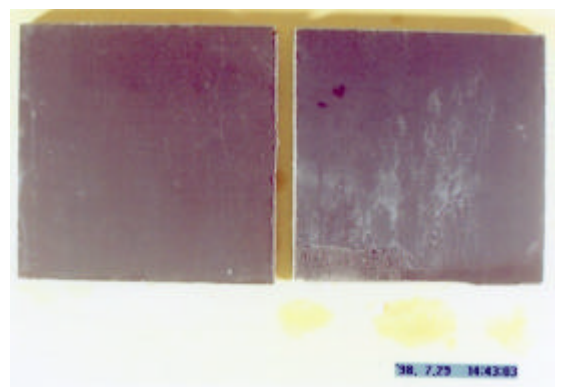
**Figure 8, Plasmadize® – Salt Spray**



**Figure 9, Nedox® – Salt Spray**



**Figure 10, Teflon® – Salt Spray**



**Figure 11, Tufram® – Salt Spray**

## DISCUSSION

It should be noted that none of the experimental results reflected the manufacturer's specifications exactly. They did not, however, seem to be biased one way or another; some properties tested higher than the manufacturer's claims while others tested lower. It seems as if the manufacturer tested their products using non-standard methods, or possibly, that the sample set in this test was not large enough.

An ideal coating for large stockpots and roasting pans is one that will release food particles from the surface while remaining on the surface of the pan for a long time under extreme conditions such as high heat and scratching with metal utensils. This correlates to low coefficients of friction, high hardness and low amounts of material lost in the Taber abrasion apparatus.

Even though most of the tests performed resulted in a very definite result, it is difficult to gauge exactly which coating is the best. When comparing wear to hardness or thickness to corrosion, it becomes an arbitrary decision. Obviously, if one coating performed better in *all* the categories than the other coatings, then it would be the best, but that is not the case here. What we see in this data is tradeoffs. A coating will be very good in one area and therefore very bad in another. For example, Nedox was extremely hard but did not do well in the wear test. Conversely, the anodized coating did well in the hardness and wear test but has a very high static coefficient of friction.

Corrosion resistance is very important to the success of the coating in the field. Wear and tear experienced in the field and cooking will contribute to the degradation of the aluminum over time. In this study, the bare aluminum did not corrode as much as expected. Instead, an aluminum oxide layer was formed, protecting the aluminum underneath. In actual field conditions, this oxide layer would be removed after each meal, exposing the aluminum to the elements. Procurement and anecdotal evidence supports that this type of care promotes corrosion and a short lifespan of cookware.

In this test, only two coatings seemed to resist corrosion altogether. The anodized coatings, the plain hard anodized coating and the Tufram. All the others, including Teflon, corroded noticeably.

Comparing figures 10 and 11, the Tufram® coating seems to withstand corrosion better than the Teflon®. The Teflon coating seems to have allowed several small sites of corrosion to migrate through the coating, the Tufram® however appears to have protected the aluminum without any signs of corrosion.

The Plasmadize® coating performed well overall in the tests. Even though it allowed some corrosion after 1000 hours of salt spray, its friction coefficients were on par with the Teflon® coating. It was, however, so thick that the coating interfered with the tolerances of the pan. This resulted in a lid that would not fit on the pan.

## CONCLUSIONS

In this study, the Tufram® coating seemed to perform the best. It had had the highest hardness, a very reasonable abrasion loss and friction coefficients that rivaled Teflon®. At a Knoop hardness value of 546, Tufram® was 27% harder than the generic anodized coating and over 500% harder than the Teflon® coating which was too soft to measure. This is an indicator that Tufram® will be resistant to sharp knife-edges and other metal utensils. Its friction properties were close to that of Teflon® indicating that the surface will release food as well. The material lost during abrasion was only 15% more than Teflon®, which is better than both the Plasmadize® and the Nedox® coatings. This coating should be field tested to insure its non-stick ability.

# QUALITATIVE

## INTRODUCTION

In addition to comparing the coatings by their physical properties, it is also important to compare them in an actual field-feeding scenario. This test compared a Teflon coating with a plasma spray coating called Plasmadize from General Magnaplate. The other coatings from the quantitative section were not tested because of increased complexity of the tests as well as a limited number of cooking equipment. Three meals were cooked on each of the pans over an MBU burner in M59 range cabinets as would be done in the field. The parameters observed included the amount and severity of stuck-on food and the amount of effort needed to remove it.

## APPROACH/SCOPE

This is a Mean Time to Failure (MTTF) test where the end of the test is based upon failure criteria for the coatings. The “time” variable is defined as number of meals used. A meal is defined as preparing food, cooking food, and cleaning and sanitizing pans. The failure criteria are based upon significant, observable wear of the coating. The parameters are as follows:

- Peeling of coating
- Flaking of coating
- Chipping of coating
- Staining
- Pitting
- Loss of “nonstick” property

When any of the above-mentioned criteria is met, the test will be conducted one further meal to determine whether the problem is stable or worsening.

## PROCEDURE

Two Army issue roaster pans, each with different non-stick coating applied to them, were tested along with an uncoated roaster pan as a control. Pan #1 was coated with a novel ceramic coating; the Plasmadize® FT4 coating is a product of General Magnaplate Corporation and it consists of a proprietary mixture of ceramics, metals and PTFE. It is FDA approved for food contact. Pan #2 was coated with a DuPont Teflon® coating by Durafilm Inc. Pan #3 was the control; it was a brand new uncoated aluminum pan made from 5052 aluminum stock.

The ovens used were M59 range cabinets to simulate field procedures. MBU burners were used as a heat source.

The pans were initially washed and sanitized using a commercial dishwasher. After each meal they were washed manually using warm water, commercial dish soap and a green scrub pad. The cleaning operations were not timed but objective observations were made on ease of cleaning.

The same three pans were used for each meal.

### **Meal 1 – Roast Beef with Carrots and Onions**

Two similar sized raw beef roasts were added to each of the three pans. The total weight of the beef was in the range of 18-24 lbs. The roasts were rubbed with salt, pepper and garlic powder. Onions and carrots were chopped and added to the pan. The pans were placed on the top of the M59 range cabinet with the cover down and the MBU on low. The roasts were baked until medium rare.

### **Meal 2 – Swiss Steaks**

Thin steaks were dipped in flour and fried on roaster covers and set aside. Tomato sauce was added to each of the pans and boiled. Fried steaks were then placed in sauce and cooked for an hour. The steaks were then removed with most of the sauce. A small amount of sauce was left to cook for 20-25 minutes to congeal and/or burn and to stick to the pans.

### **Meal 3 – Chili Con Carne**

Roaster pans were filled  $\frac{3}{4}$  with chili con carne. The chili was brought to a boil and simmered for 2 hours. Most of the chili was served, a small amount was retained to burn and stick to the pans.

## **RESULTS**

### Photos

The procedures and results of each meal were documented in digital pictures. These pictures are arranged in the following pages in grids. In each grid, the left column shows the progression of the Plasmadize® coated pan from start to finish, the middle column shows the Teflon® coated pan and the right column shows the uncoated pan. Going down the rows, the top row shows the condition of the pans before cooking, the middle row shows the stress created by cooking and the bottom row shows the condition of the pans after a gentle rinse.

### Test 1

Figures 12-20 depict the results of meal 1. In figures 12-14, we can see that the pans are brand new and the coatings are newly applied. Figure 16 shows the typical cooking of the roasts. The carrots and onions were added too early so they ended up burning and becoming charred. This became mixed with the juices from the beef to form a layer of sticky carbon on the bottom of the pan. When the roasts were removed, the carbon layer covered almost the whole bottom with the exception of where the roasts had been. This is shown in figure 15. Each pan was pre-washed by adding water directly to the hot pan as shown in figure 17. Doing this dissolved much of the carbon, allowing for easier cleaning and sanitizing. Whether or not this practice will be executed in the field is

unclear but it known to be a reliable way to remove burnt food from pans. The pre-wash did not augment the data because any damage to the coating had already taken place, pre-washing simply allowed for slightly easier cleaning in the distant future. The procedure was carried out identically for each pan. Figures 18-20 show the condition of the pans after the pre-wash. It can be seen in figure 20 that a significant portion of the carbon remained stuck to the uncoated pan while less carbon remained stuck to the Teflon® in figure 19, and almost none to the Plasmadize® in figure 7. The Plasmadize® was, however, significantly stained by the carbon deposits.

The cleaning and sanitizing process was achieved manually. This was necessary to gauge which coating exhibited the best release properties. After meal 1, cleaning the Plasmadize® (pan #1) coating was very easy. There was no food stuck to the pan and only a small layer of grease that needed to be washed off. The stains could not be removed from the coating. There was no evidence of peeling, pitting or cracking of the coating.

The Teflon® coating (pan #2) was also easy to clean. There were some solids that were loosely stuck to the coating but a gentle sponge was enough to release them. There were no stains, but a slight discoloration was observed. There was no evidence of peeling, pitting or cracking of the coating.

The uncoated pan (pan #3) was very difficult to clean. The surface was coated with carbon deposits from the burnt food. Some of carbon became impregnated in the pores of the metal and could not be removed at all. It took significantly longer to clean this pan and significantly more effort as well.

**Test 1, Roast Beef with Carrots and Onions.**



**Figure 12, New Plasmadize coating**



**Figure 13, New Teflon coating**



**Figure 14, New uncoated pan**



**Figure 15, Food burnt on Plasmadize**



**Figure 16, Food burnt on Teflon**



**Figure 17, Food burnt on Teflon with water added**



**Figure 18, Plasmadize, pre-washed**



**Figure 19, Teflon, pre washed**



**Figure 20, Uncoated, pre-washed**

## Test 2

Figures 10-18 show the results of the second meal, Swiss Steaks. Swiss steaks are made by flouring and frying beefsteaks and then braising them in tomato sauce. The lids of the pans were used to fry the steaks while the roaster pans themselves were used to cook the tomato sauce and then braise the steak.

Figures 10, 11 and 12 show the initial condition of the pans. It is clear that the pans did not become totally clean from the prior meal, the uncoated pan especially. Black marks indicate carbon deposits into the pores of the metal. In a field situation a soldier would be told to scrape the pan with hard steel wool or a steel mesh pad until metal shows through. This procedure was not followed so as to maintain uniformity across the test samples.

Figures 13, 14 and 15 show the leftover tomato sauce from the Swiss steak meal. The acids from the tomato sauce coupled with the heat of long term cooking are the stresses for this test. Not much sauce actually stuck to the pans. By filling up the pans with warm water and dumping it out, we can observe the amount of food that stuck to the pan.

Figures 16, 17 and 18 show that most of the tomato sauce dissolved into the first gentle rinse. The sauce that remained was easily removed with a gentle sponge. However there was some sauce stuck to the sides of the pans. This was the easiest to remove from the Teflon® pans, followed by the Plasmadize and the uncoated pans. It was, however not that hard to remove the stuck on sauce from the uncoated pans. The black char left over from the last test was still stuck to the pan and was hard to remove from the corners.

The Teflon® coating began to peel from the corners as shown in figure 19. It cannot be determined whether this was related to stirring with a metal utensil, the effect of the hot tomato sauce or scrubbing action but it is assumed that all of these factors played a part. Instead of ending the test at this point, another meal was planned to observe the effects of the peeling and whether or not the condition would worsen.

## Test 2, Swiss Steak



Figure 21, Plasmadize initial condition



Figure 22, Teflon initial condition



Figure 23, Uncoated initial condition



Figure 24, Plasmadize w/ baked on sauce



Figure 25, Teflon w/ baked on sauce



Figure 26, Uncoated w/ baked on sauce



Figure 27, Gently rinsed Plasmadize



Figure 28, Gently rinsed Teflon



Figure 29, Gently rinsed uncoated



**Figure 30, Teflon Peeling at the corners and bends**

### Test 3

The third meal consisted of chili con carne. This is also a food known to be high in fats and acids. Figures 20-28 show the results of this test. Figures 20-23 show that even though the pans are clean, the Plasmadize® coating is still stained, the Teflon® coating is peeling in the corners and the uncoated pan has almost irremovable carbon deposits.

After cooking a small portion of chili for 20 minutes after the bulk was served, food became stuck to the sides of the pans. Figures 24 and 25 show how even though the food seemed to be stuck to the sides of pans 1 and 2, it peeled off with ease. This demonstrates excellent release properties, as one would expect from products containing PTFE.

Figures 26-28 show the pans after cleaning; pans 1 and 2 were effortless to clean. Pan 3, the uncoated pan, was not easy to clean at all. Chili residue was firmly attached to the sidewall of the pan. It took significantly longer to clean with significantly more effort. Figures 28 shows that enough time and effort was eventually spent on the pan over the three cleanings to remove most of the burnt on food from the first meal.

### Test 3, Chili Con Carne



Figure 31, Plasmadize initial condition



Figure 32, Teflon initial condition



Figure 33, Uncoated initial condition



Figure 34, Congealed food peels off



Figure 35, Congealed food lifts off



Figure 36, Food is stuck on



Figure 37, Cleaned Plasmadize



Figure 38, Cleaned Teflon



Figure 39, Cleaned uncoated

**Table 4, Results Summary**

<b>Coating</b>	<b>Non Stick</b>	<b>Adherence</b>	<b>Appearance</b>	<b>Comments</b>
Teflon	Non-stick property was conserved through all 3 tests	Began flaking after second meal and continued to flake	Somewhat stained after each meal	Teflon as a brand name is applied differently by different contractors
Plasmadize	Somewhat non-stick, no degradation over time	Good	Became increasingly stained	This coating is so thick that it is hard to put the cover on.
Uncoated	Impossible to remove burnt food, very hard to remove baked on food.	n/ap	Some discoloration due to heat. Black char from burnt food	

## RESULTS / CONCLUSIONS

The results of the test are shown in Table 1. Neither one of the two coatings passed this qualitative test. The mean time to failure for each coating was two meals. Although the Teflon® coating applied by Durafilm Inc. retained its non-stick property throughout the test, it began to flake and peel after just two meals and washings. It also incurred several stains. The Plasmadize® coating applied by General Magnaplate Inc. incurred several stains and some mild pitting. The stains on this pan were more prevalent because of the light color of the coating. Stains are not a sanitation issue but they are an annoyance that can very easily be mistaken for a sanitation issue in the field. Soldiers in the field may be inclined to wash and scrub a stained pan until it looked clean. The most noticeable problem with this coating however is its thickness. The coating is so thick that the cover does not fit on the pan.

More testing should be conducted on a variety of different coatings. Several variations on Teflon® and Plasmadize® exist that have very different properties than the variety tested. Furthermore, there are other coating families such as anodized, metallic, quasicrystal and diamond coatings that should be tested qualitatively. Even though both these products failed this test, there is confidence that an adequate product will be found for the application.

## OVERALL RESULTS AND CONCLUSIONS

The general trend displayed in these two tests suggests that commercial coatings are not yet sufficient for use in an Army field-feeding scenario. Both the quantitative and the qualitative seemed to discount the use of Teflon™ or another pure PTFE coating. Although one can argue that the application of this coating was not of the highest quality, choosing a coating that can be applied by so many contractors, large and small, experienced and inexperienced would be a risk. Furthermore, the general shape of the pan, with the steep filleted sides, does not lend itself to a PTFE application. The fillet is an obvious site of stress for the coating as was shown by almost immediate flaking and peeling.

Each of the other coatings except for the Tuftram® coating were discounted by a failure in at least one test. The Nedox® failed the salt spray test, the Plazmadize® coating was too thick, and the friction coefficient of the anodized coating was too high. The qualitative tests discounted the plasma spray coating because of its tendency for becoming stained as well as showing signs of pitting.

More tests should be conducted on the Tuftram® coating. This coating seems promising as a durable, non-stick coating for use in the field.